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A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING THE AN/ASN 43 FOR --ETC(U)
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Technical Memorandum 8-80

A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING THE AN/ASN 43 FOR DOPPLER (AN/ASN 128) INSTALLATION AND CALIBRATION

Thomas L. Frezell
Peter J. Grazaitis

April 1980
AMCMS Code 612716.H700011

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U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Memorandum 8-80

2. GOVT ACCESSION NO.
AD-A085605

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING THE AN/ASN 43 FOR DOPPLER (AN/ASN 128) INSTALLATION AND CALIBRATION,

5. TYPE OF REPORT & PERIOD COVERED
(9) Final Rept.,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) Thomas L./Frezell
Peter J./Grazaitis

8. CONTRACT OR GRANT NUMBER(s)
(12) 27

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Human Engineering Laboratory
Aberdeen Proving Ground, MD 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
AMCMS Code 612716.H700011

11. CONTROLLING OFFICE NAME AND ADDRESS
(11)

12. REPORT DATE
Apr[redacted]80

13. NUMBER OF PAGES
25

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(14) HEL-TM-8-80

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Doppler (AN/ASN 128) Installation
Flux Valve Alignment
Navigation Systems
Navigation Errors
AN/ASN 43 Alignment
Heading Reference

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report deals with a computer assisted methodology to be used in aligning an AN/ASN 43 magnetic flux valve. This procedure is critical for the calibration and alignment of a doppler navigation system.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

171250

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AMCMS Code 612716.H700011 Technical Memorandum 8-80

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CONTENTS

A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING THE AN/ASN 43 FOR DOPPLER (AN/ASN 128) INSTALLATION AND CALIBRATION

INTRODUCTION

With the procurement of a doppler navigation system by the US Army for installation on certain Army aircraft, it is imperative that maximum fidelity be attained from the aircraft heading reference system. This report deals only with the alignment of an AN/ASN 43; however, the methodology described is appropriate for aligning and calibrating other magnetic reference systems.

ALIGNMENT

A detailed method for aligning the magnetic flux system is contained in the AN/ASN-128 Doppler Installation and Acceptance Testing Manual.[1] This section will only serve to supplement and enhance the base document.

In initiating an alignment procedure, a precise flight test course should be established for use throughout the entire procedure. Many factors exist which must be considered in establishing a course. Several of these factors are listed below:

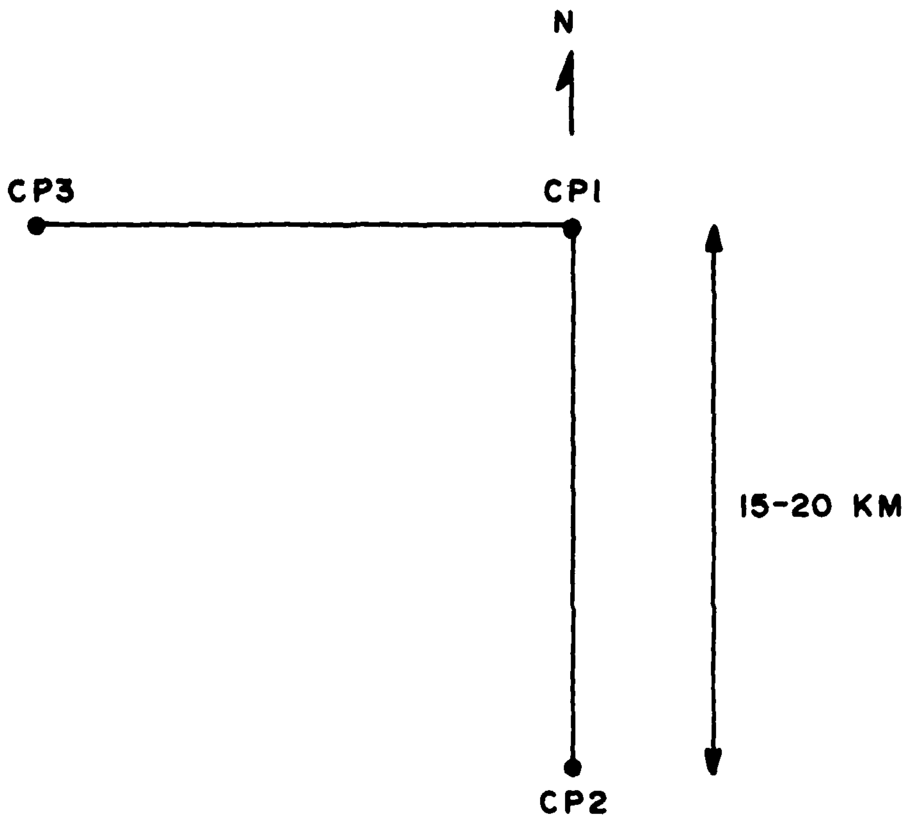
1. Select check points (CPs) that can be easily identified at a distance of several kilometers when flying the test course.

2. Select a CP that is easily identified on a large scale map to assure the greatest accuracy in plotting its coordinates.

3. Design the test course so that the CPs selected are close to magnetic North-South and East-West headings. This will help in resolving errors by holding the number of possible variables to a minimum.

4. The CPs should be located approximately 15 to 20 kilometers apart. A graphic presentation of an ideal flight test course is depicted in Figure 1.

[1] US Army Avionics Research & Development Activity. Installation and Acceptance Testing of Navigational Set, Doppler AN/ASN-128, Specification Number AV-IT5800-001A, Fort Monmouth, NJ, 9 March 1979.



LEG 1 = CP2 - CP1
LEG 2 = CP1 - CP3
LEG 3 = CP3 - CP1
LEG 4 = CP1 - CP2

Figure 1. Graphic presentation of an ideal flight test course.

5. In using the AN/ASN 128 to enter the magnetic variation of the flight area, the Clark 1866 code of CL6 should be used anywhere within the continental United States. Outside the continental United States, other applicable codes should be used. The Defense Mapping Agency's Index of Grids, Datums and Spheroids[2] should be used to determine what code is appropriate.

6. The installation and acceptance document suggests using the average value by flying three test patterns and computing a mean value. If good reliability is determined early in the flight pattern, then one trip around the course should provide accurate data to perform the necessary alignment calculations.

7. The same individual should determine the aircraft's exact time over the check point for recording and storage to assure consistency and reliability. This will also eliminate another variable.

8. The alignment procedure is a precise and time consuming task. The accurate alignment of the flux system will yield greater system performance.

ALIGNMENT EQUATIONS AND COMPUTATIONS

This section deals with equations and calculations necessary in aligning the aircraft flux system. The majority of the data provided here is also contained in the installation and acceptance document. Some areas have been clarified to a greater extent, and some of the acceptance document errors have been corrected. It is included to assist those who do not have computer facilities or the background to utilize the computer assisted methodology that will follow this section.

The computations performed will use coordinate values supplied in the installation and acceptance document.

The schematic depicted in Figure 2 would indicate a flight from CP 1 to CP 2 and return to CP 1, thus allowing two sets of data points to be generated; i.e. actual (plotted) and indicated (displayed by doppler upon overflight of plotted point). Table 1 shows the UTM actual and indicated coordinates.

[2]Defense Mapping Agency Topographic Center. Grid, datum, and spheriod information, Plate I. DMA Stock No. DATMX52411C1. Code 40220, Washington, DC, 20315, 2 September 76.

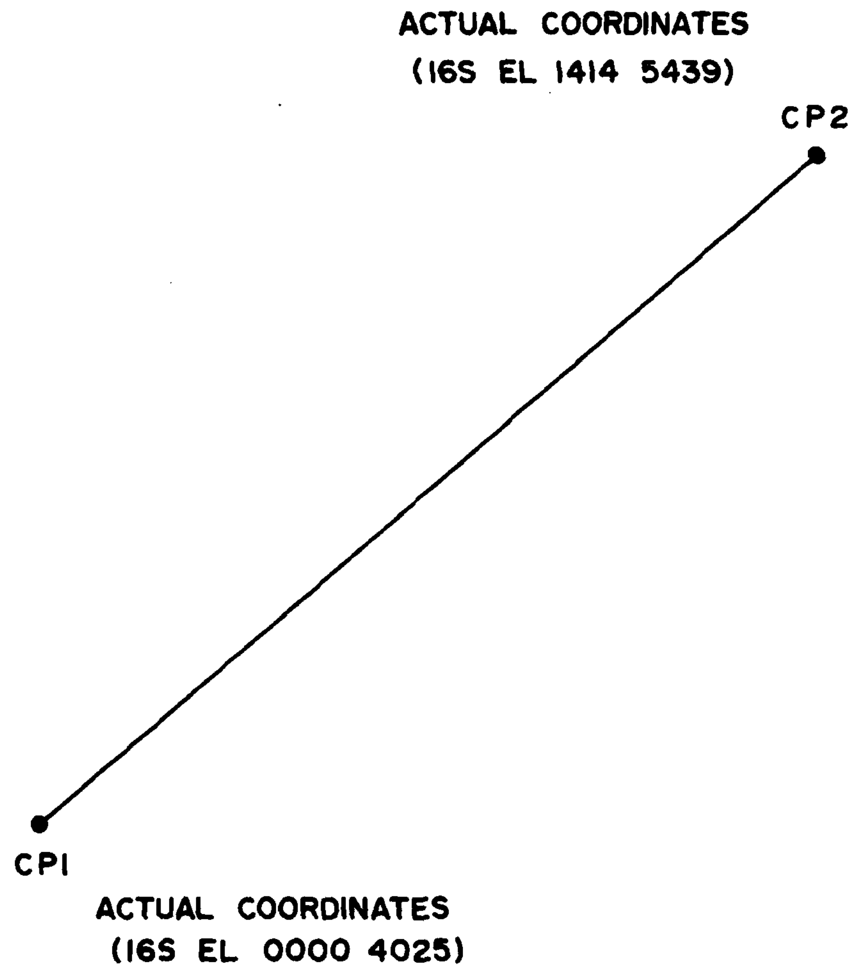


Figure 2. Initial test leg of flight course.

TABLE 1

UTM Actual and UTM Indicated Coordinates

	UTM Actual Coordinates				UTM Indicated Coordinates			
Check Point	Grid Zone	Area	Easting (E)	Northing (N)	Grid Zone	Area	Easting (E)	Northing (N)
1	16S	EL	0000	4025	16S	EL	0006	4022
2	16S	EL	1414	5439	16S	EL	1438	5432
3								
•								
•								
•								
•								

Equations and Calculations

Actual Distance Traveled CP1 ⟶ CP2

D_T = Distance traveled
(m) = Meters
Δ = Delta; i.e., change or difference

$$D_T(m) = c = \sqrt{a^2+b^2} \text{ X10 where } a = \begin{array}{l} CP2(E)=1414 \\ CP1(E)=\underline{0000} \\ \Delta E \quad =1414 \end{array} \quad b = \begin{array}{l} CP2(N)=5439 \\ CP1(N)=\underline{4025} \\ \Delta N \quad =1414 \end{array}$$

$$= \sqrt{(1414)^2+(1414)^2} \text{ X10}$$

$$= \sqrt{3998792} \text{ X10}$$

= 20,000m

= 20km

Actual Bearing Angle (Deg)

Where y = northing distance meters (m)

x = easting distance meters (m)

$$\beta = \operatorname{Tan}^{-1} \frac{y}{x}$$

$$\beta = \operatorname{Tan}^{-1} \frac{1414}{1414}$$

$$\beta = 45^\circ$$

Easting Error (meters) = $\varepsilon P_E(m)$ i = indicated

$$\varepsilon P_E(m) = \left[(E_{2i} - E_2) - (E_{1i} - E_1)\right] X10$$

$$\varepsilon P_E(m) = \left[(1438 - 1414) - (0006 - 0000)\right] X10$$

$$= \left[(24) - (6)\right] X10$$

$$\varepsilon P_E = 180 \text{ meters}$$

Northing Error

$$\varepsilon P_N(m) = \left[(N_{2i} - N_2) - (N_{1i} - N_1)\right] X10$$

$$= \left[(5432 - 5439) - (4022 - 4025)\right] X10$$

$$= \left[(-7) - (-3)\right] X10$$

$$\varepsilon P_N = -40 \text{ meters.}$$

Using the Easting and Northing error values, as well as the actual bearing angle, we now compute the Along Track Error (εAT) and the Cross Track Error (εCT) in meters and percent.

Where

$$\varepsilon AT(m) = \varepsilon P_N \cos\beta + \varepsilon P_E \sin\beta$$

$$= -40 \cos 45^\circ + 180 \sin 45^\circ$$

$$\varepsilon AT(m) = 98.980 \text{ meters}$$

$$\varepsilon AT(\%) = \frac{\varepsilon AT(m)}{D_T(m)} \times 100 = \frac{98.980}{20{,}000} = .49\%$$

The $\varepsilon AT\%$ should not exceed 2.0% of D_T. Repair or realignment should be considered if error is much more than 1.0% of D_T.

Cross Track Error:

$$\varepsilon C_T(m) = -\varepsilon P_N \sin\beta + \varepsilon P_E \cos\beta$$

$$= -(-40) \sin 45^\circ + 180 \cos 45^\circ$$

$$= 155.54$$

$$\varepsilon C_T(\%) = \frac{\varepsilon C_T(m)}{D_T(m)} \times 100$$

$$= \frac{155.54}{20{,}000} \times 100$$

$$\varepsilon C_T(\%) = .77\%$$

$\varepsilon C_T\%$ should not exceed 5.0% of D_T. The authors believe that the $\varepsilon C_T\%$ should not exceed 2.5% of D_T in order to consider the system reliable enough for accurate navigation.

FLIGHT TEST DATA REDUCTION AND ERROR DETERMINATION

This section will present the calculation methodology for reducing the flight data. All the equations used are taken from the Installation and Acceptance Testing Document.

1. Calculate the azimuth angle flown on each leg by computing the change in northing ΔN and easting ΔE. In order to compute this angle in the correct direction, we must use the following values:

$$\text{If } \Delta E \geq 0 \text{ then } \Theta = 90° - \text{Tan}^{-1} \frac{\Delta N}{\Delta E} \pm \text{Magnetic Variation}$$

$$\text{If } \Delta E < 0 \text{ then } \Theta = 270 - \text{Tan}^{-1} \frac{\Delta N}{\Delta E} \pm \text{Magnetic Variation}$$

2. If using more than one set of values, group the azimuth angles into north, south, east, and west groups.

3. Determine the error for each leg by subtracting the calculated true azimuth from doppler read values.

$$\text{i.e. } \varepsilon = \Theta - \Theta \text{ true}$$

4. Calculate the mean error for each leg; i.e. (N,S,E,W):

$$\bar{\varepsilon} = \frac{1}{N} \Sigma \varepsilon$$

5. Once the mean is calculated for each leg, determine that the error (ε) in each leg is not greater than 1° from the calculated mean ($\bar{\varepsilon}$). The acceptance document recommends that the mean be recalculated leaving out the leg with the mean error difference of >1°, or reflying the course to obtain a new set of data points.

6. Calculate the index error by:

$$\bar{\varepsilon}_I = \frac{\bar{\varepsilon}_N + \bar{\varepsilon}_S + \bar{\varepsilon}_E + \bar{\varepsilon}_W}{4}$$

7. Calculate the <u>N/S</u> and <u>E/W</u> compensation displacement by:

$$\varepsilon_{N/S} = \frac{\bar{\varepsilon}_N - \bar{\varepsilon}_S}{2}$$

$$\text{and } \varepsilon_{E/W} = \frac{\bar{\varepsilon}_E - \bar{\varepsilon}_W}{2}$$

8. The value calculated for the index error ($\bar{\varepsilon}I$) must now be corrected from the AN/ASN 43. Accuracy to be obtained should be within $\pm 0.1°$.

9. The N/S and E/W compensation displacement error should be corrected to within ± 0.1°.

One will quickly realize that the alignment procedure is a very time consuming process. Not only must one spend many hours in flight, but the calculations required to determine system error and compass alignment and compensation values are arduous and prone to error.

In the process of installing and aligning two doppler systems, the US Army Human Engineering Laboratory developed a computer program that will do all calculations and print out all information described thus far.

NOTE: All calculations are based on a flight within one 100,000 meter square. If the flight area should include more than one 100,000 meter square, one should take this into account when entering coordinate values. Neither program will recognize a change in the 100,000 meter square.

THEORY AND OPERATION OF THE PROGRAM

The program is written in Basic for the Hewlett Packard Model HP-9830A programmable desktop calculator. The calculator will calculate and print pertinent data for calibration purposes. A copy of the Basic program is included in Appendix A. A sample of the Basic program printout is contained in Appendix B.

It is assumed that you are flying to three points in a manner similar to the figure below (Figure 3).

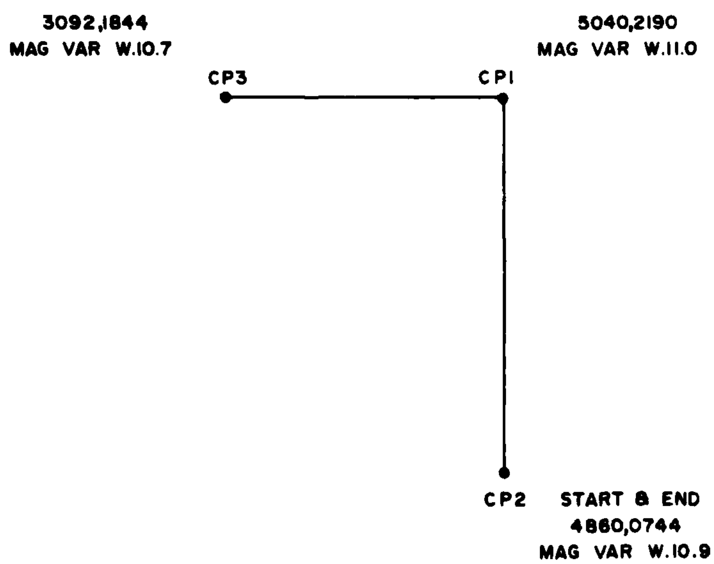


Figure 3. Flight test course and associated coordinate and magnetic variations.

The easting and northing coordinates and the magnetic variance associated with the three flight points must be known (Figure 3).

The flight pattern is as follows: Take off from point 2, proceed to point 1, proceed to point 3, return to point 1, and return to point 2 where the flight ends. As the flight proceeds to the various points, the doppler coordinates should be recorded. The coordinate values will probably be different from the reference coordinates. The doppler and reference coordinates should be set up in a table (Table 2) for ease in entering the needed data into the computer for processing.

TABLE 2

Doppler and Reference Coordinates Setup

	Plotted Reference Points		Recorded Doppler Points		
Point	Easting	Northing	Easting	Northing	Magnetic Var. of End Point
2-1	4860	0744	5010	2124	11.0
1-3	5040	2190	3187	1935	10.7
3-1	3092	1844	4930	2274	11.0
1-2	5040	2190	4840	0833	10.9

Table 2 relates directly to the flight path taken. This information is keyed into the computer for processing but in a slightly different line order. When the program is executed, the program will prompt the user four times for input data. A typical prompt is listed below:

Input PT1 to PT2 & Magnetic Variation

The user would type in the known easting and northing coordinates for point 1, then the doppler easting and northing coordinates, and the magnetic variation associated with point 2 (the point one is flying to). The input stream is keyed in via the keyboard followed by an execute (carriage return). The user's response to the prompt is taken from Table 2 and appears below:

5040,2190,4840,0833,10.9(ex)

The user must take care to input the data correctly according to the prompts. A sample of the four computer prompts and the proper user responses are given in the exact order as they will appear below. The responses are based on sample data contained in Table 2.

(Computer Prompt)	Input PT1 to PT2 & Magnetic Variation
(User Response)	5040,2190,4840,0833,10.9(ex)
(Computer Prompt)	Input PT2 to PT1 & Magnetic Variation
(User Response)	4860,0744,5010,2124,11.0(ex)
(Computer Prompt)	Input PT1 to PT3 & Magnetic Variation
(User Response)	5040,2190,3187,1935,10.7(ex)
(Computer Prompt)	Input PT3 to PT1 & Magnetic Variation
(User Response)	3092,1844,4930,2274,11.0(ex)

A large portion of the program is made up of output statements. The program should be suitable for a handheld programmable calculator, such as the HP-41C, provided that it has sufficient memory. This would be ideal for use directly in the field; however, no attempt has been made to convert it. Although the HP-9830A is somewhat portable, the name is misleading. It is more of a minicomputer than a calculator. It is not battery operated and runs on a 110V AC line making it difficult to use in the field.

It should be very easy to convert the program written for the HP-9830A calculator into standard Basic. Most of the statements do not require modification. The changes that are necessary should be both minor and obvious. Since everyone does not use Basic, the program was converted to ForTran. The ForTran program was written for the PDP-11 series computer from Digital Equipment Corporation under the RT-11 operating system. This machine uses a 16-bit word length. There should be no major problem in running this program on any other machine using the ForTran program. A minor formatting problem might occur where the real variable Array C is used to output some character data on the A4 format. On machines with larger word lengths, this A4 format should be changed to accomodate the larger character storing capacity.

The ForTran program directs all messages and all inputs via logical unit 5. On the PDP-11 series machine, this is the consol terminal. All output is directed to logical unit 6 which is the system line printer on the PDP-11 series machines. If your machine uses another logical unit numbers for the terminal and line printer, change the variables LO (Logical Output) and LI (Logical Input) to what they should be for your machine.

The ForTran program prompts the user interactively as before, but the input must adhere to the input format listed below. A copy of the ForTran program and its output appears in Appendixes C and D.

XXXXX,XXXXX,XXXXX,XXXXX,XX.X(CR)

05040,02190,04840,00833,10.9(CR)

APPENDIX A

THE BASIC PROGRAM

```
5 DIM A[4,13],A$[80],B[4,5]
10 DISP "INPUT PT1 TO PT2 & MAG. VARIANCE";
15 INPUT A[1,1],A[1,2],A[1,3],A[1,4],A[1,5]
20 DISP "INPUT PT2 TO PT1 & MAG. VARIANCE";
25 INPUT A[2,1],A[2,2],A[2,3],A[2,4],A[2,5]
30 DISP "INPUT PT1 TO PT3 AND MAG. VARIANCE";
35 INPUT A[3,1],A[3,2],A[3,3],A[3,4],A[3,5]
40 DISP "INPUT PT3 TO PT1 & MAG. VARIANCE";
45 INPUT A[4,1],A[4,2],A[4,3],A[4,4],A[4,5]
50 DEG
55 FOR J=1 TO 4
60 IF J=2 OR J=4 THEN 75
65 A[J,6]=SQR((A[J,1]-A[J+1,1])↑2+(A[J,2]-A[J+1,2])↑2)*10
70 A[J+1,6]=A[J,6]
75 B1=SQR((A[J,2]-A[J+(-1)↑(J+1),2])↑2)
80 B2=SQR((A[J,1]-A[J+(-1)↑(J+1),1])↑2)
85 IF A[J+(-1)↑(J+1),1]>A[J,1] AND A[J+(-1)↑(J+1),2]>A[J,2] THEN 105
90 IF A[J+(-1)↑(J+1),2]>A[J,2] AND A[J+(-1)↑(J+1),1]<A[J,1] THEN 115
95 IF A[J+(-1)↑(J+1),2]<A[J,2] AND A[J+(-1)↑(J+1),1]<A[J,1] THEN 125
100 IF A[J+(-1)↑(J+1),2]<A[J,2] AND A[J+(-1)↑(J+1),1]>A[J,1] THEN 135
105 A[J,7]=ATN(B2/B1)+A[J,5]
110 GOTO 140
115 A[J,7]=ATN(B2/B1)+A[J,5]+270
120 GOTO 140
125 A[J,7]=ATN(B2/B1)+A[J,5]+180
130 GOTO 140
135 A[J,7]=ATN(B2/B1)+A[J,5]+90
140 A[J,8]=((A[J,3]-A[J+(-1)↑(J+1),1])-(A[J+(-1)↑(J+1),3]-A[J,1]))*10
145 A[J,9]=((A[J,4]-A[J+(-1)↑(J+1),2])-(A[J+(-1)↑(J+1),4]-A[J,2]))*10
150 A[J,10]=A[J,9]*COS(A[J,7])+A[J,8]*SIN(A[J,7])
155 A[J,11]=(A[J,10]/A[J,6])*100
160 A[J,12]=A[J,8]*COS(A[J,7])-A[J,9]*SIN(A[J,7])
165 A[J,13]=(A[J,12]/A[J,6])*100
170 NEXT J
175 WRITE (15,180)
180 FORMAT 34X,"CALCULATIONS",2/,36X,"TABLE 1",/
185 A$[1,74]="            ACTUAL      INDICATED    MAGNETIC        ACTUAL  BEARING"
190 A$[66,80]="EAST     NORTH"
195 WRITE (15,200)A$
200 FORMAT B
205 A$[1,61]="LEG      COORDINATE    COORDINATE  DIFFERENCE     DISTANCE  ANGLE"
210 A$[62,80]="     ERROR    ERROR"
215 WRITE (15,220)A$
220 FORMAT B,/
225 PRINT
230 WRITE (15,235)A[1,1],A[1,2],A[1,3],A[1,4],A[1,5],A[1,6],A[1,7],A[1,8],A[1,9]
235 FORMAT "1-2",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
240 WRITE (15,245)A[2,1],A[2,2],A[2,3],A[2,4],A[2,5],A[2,6],A[2,7],A[2,8],A[2,9]
245 FORMAT "2-1",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
250 WRITE (15,255)A[3,1],A[3,2],A[3,3],A[3,4],A[3,5],A[3,6],A[3,7],A[3,8],A[3,9]
255 FORMAT "1-3",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
260 WRITE (15,265)A[4,1],A[4,2],A[4,3],A[4,4],A[4,5],A[4,6],A[4,7],A[4,8],A[4,9]
265 FORMAT "3-1",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
270 WRITE (15,275)
```

(Continued)

```
275 FORMAT /,36X,"TABLE 2",/
280 WRITE (15,285)
285 FORMAT 13X,"ALONG TRACK ERROR",19X,"CROSS TRACK ERROR"
290 WRITE (15,295)
295 FORMAT "LEG",9X,"(M)",13X,"(%)",17X,"(M)",13X,"(%)",/
300 WRITE (15,305)A[1,10],A[1,11],A[1,12],A[1,13]
305 FORMAT "1-2",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
310 WRITE (15,315)A[2,10],A[2,11],A[2,12],A[2,13]
315 FORMAT "2-1",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
320 WRITE (15,325)A[3,10],A[3,11],A[3,12],A[3,13]
325 FORMAT "1-3",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
330 WRITE (15,335)A[4,10],A[4,11],A[4,12],A[4,13]
335 FORMAT "3-1",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
340 FOR J=1 TO 4
345 B1=A[J+(-1)↑(J+1),2]-A[J,2]
350 B2=A[J+(-1)↑(J+1),1]-A[J,1]
355 IF B2<0 THEN 370
360 B[J,4]=90-ATN(B1/B2)+A[J,5]
365 GOTO 375
370 B[J,4]=270-ATN(B1/B2)+A[J,5]
375 B[J,1]=A[J,4]-A[J,2]
380 B[J,2]=A[J,3]-A[J,1]
385 IF B[J,2]<0 THEN 400
390 B[J,3]=90-ATN(B[J,1]/B[J,2])+A[J,5]
391 IF B[J,3]<360 THEN 405
392 B[J,3]=B[J,3]-360
395 GOTO 405
400 B[J,3]=270-ATN(B[J,1]/B[J,2])+A[J,5]
401 IF B[J,3]<360 THEN 405
402 B[J,3]=B[J,3]-360
405 B[J,5]=B[J,3]-B[J,4]
410 NEXT J
415 PRINT
420 WRITE (15,425)
425 FORMAT 36X,"TABLE 3",/
430 A$[1,80]="LEG   DIRECTION     DEL NORTH    DEL EAST   THETA"
435 A$[50,80]="     THETA TRUE   ERROR"
440 WRITE (15,445)A$
445 FORMAT B
450 PRINT
455 WRITE (15,460)B[1,1],B[1,2],B[1,3],B[1,4],B[1,5]
460 FORMAT "1-2",5X,"SOUTH",8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
465 WRITE (15,470)B[2,1],B[2,2],B[2,3],B[2,4],B[2,5]
470 FORMAT "2-1",5X,"NORTH",8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
475 WRITE (15,480)B[3,1],B[3,2],B[3,3],B[3,4],B[3,5]
480 FORMAT "1-3",5X,"EAST",9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
485 WRITE (15,490)B[4,1],B[4,2],B[4,3],B[4,4],B[4,5]
490 FORMAT "3-1",5X,"WEST",9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1,2/
495 WRITE (15,500)(B[2,5]-B[1,5])/2
500 FORMAT "ERROR-N/S",5X,F10.2,/
505 WRITE (15,510)(B[3,5]-B[4,5])/2
510 FORMAT "ERROR-E/W",5X,F10.2,/
515 WRITE (15,520)(B[1,5]+B[2,5]+B[3,5]+B[4,5])/4
520 FORMAT "INDEX ERROR",5X,F10.2
525 END
```

APPENDIX B

BASIC PROGRAM PRINTOUT

CALCULATIONS

TABLE 1

LEG	ACTUAL COORDINATE	INDICATED COORDINATE	MAGNETIC DIFFERENCE	ACTUAL DISTANCE	BEARING ANGLE	EAST ERROR	NORTH ERROR
1-2	5040.-2190.	4840.- 833.	10.9	14572.	198.0	100.0	1550.0
2-1	4860.- 744.	5010.-2124.	11.0	14572.	18.1	-100.0	-1550.0
1-3	5040.-2190.	3187.-1935.	10.7	19785.	270.6	2050.0	70.0
3-1	3092.-1844.	4930.-2274.	11.0	19785.	90.9	-2050.0	-70.0

TABLE 2

LEG	ALONG TRACK ERROR (M)	ALONG TRACK ERROR (%)	CROSS TRACK ERROR (M)	CROSS TRACK ERROR (%)
1-2	-1505.1	-10.33	383.7	2.63
2-1	-1504.4	-10.32	386.4	2.65
1-3	-2049.1	-10.36	92.3	0.47
3-1	-2048.6	-10.35	103.1	0.52

TABLE 3

LEG	DIRECTION	DEL NORTH	DEL EAST	THETA	THETA TRUE	ERROR
1-2	SOUTH	-1357.0	-200.0	199.3	198.0	1.3
2-1	NORTH	1380.0	150.0	17.2	18.1	-0.9
1-3	EAST	-255.0	-1853.0	272.9	270.6	2.2
3-1	WEST	430.0	1838.0	87.8	90.9	-3.1

ERROR-N/S -1.09

ERROR-E/W 2.67

INDEX ERROR -0.12

APPENDIX C

FORTRAN PROGRAM

```
              DIMENSION A(4,13),B(4,5),C(4)
              DATA C/'1-2 ','2-1 ','1-3 ','3-1 '/
              LI=5
              LO=6
              WRITE(LI,1)
      1       FORMAT(1H ,'INPUT PT1 TO PT2 & MAGNETIC VARIANCE?')
              READ(LI,2)(A(1,J),J=1,5)
      2       FORMAT(4(F5.0,X),F4.1)
              WRITE(LI,3)
      3       FORMAT(1H ,'INPUT PT2 TO PT1 & MAGNETIC VARIANCE?')
              READ(LI,2)(A(2,J),J=1,5)
              WRITE(LI,4)
      4       FORMAT(1H ,'INPUT PT1 TO PT3 & MAGNETIC VARIANCE?')
              READ(LI,2)(A(3,J),J=1,5)
              WRITE(LI,5)
      5       FORMAT(1H ,'INPUT PT3 TO PT1 & MAGNETIC VARIANCE?')
              READ(LI,2)(A(4,J),J=1,5)
              DO 100 J=1,4
              IF(J.EQ.2.OR.J.EQ.4)GOTO 75
              A(J,6)=SQRT((A(J,1)-A(J+1,1))**2+(A(J,2)-A(J+1,2))**2)*10.0
              A(J+1,6)=A(J,6)
      75      B1=SQRT((A(J,2)-A(J+(-1)**(J+1),2))**2)
              B2=SQRT((A(J,1)-A(J+(-1)**(J+1),1))**2)
              IF(A(J+(-1)**(J+1),1).GT.A(J,1).AND.A(J+(-1)**(J+1),2).GT.
             *   A(J,2))GOTO 105
              IF(A(J+(-1)**(J+1),2).GT.A(J,2).AND.A(J+(-1)**(J+1),1).LT.
             *   A(J,1))GOTO 115
              IF(A(J+(-1)**(J+1),2).LT.A(J,2).AND.A(J+(-1)**(J+1),1).LT.
             *   A(J,1))GOTO 125
              IF(A(J+(-1)**(J+1),2).LT.A(J,2).AND.A(J+(-1)**(J+1),1).GT.
             *   A(J,1))GOTO 135
      105     A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)
              GOTO 140
      115     A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+270.0
              GOTO 140
      125     A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+180.0
              GOTO 140
      135     A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+90.0
      140     A(J,8)=((A(J,3)-A(J+(-1)**(J+1),1))-(A(J+(-1)**(J+1),3)-
             *   A(J,1)))*10.0
              A(J,9)=((A(J,4)-A(J+(-1)**(J+1),2))-(A(J+(-1)**(J+1),4)-
             *   A(J,2)))*10.0
              A(J,10)=A(J,9)*COS(A(J,7)*.017453)+A(J,8)*
             *   SIN(A(J,7)*.017453)
              A(J,11)=(A(J,10)/A(J,6))*100.0
              A(J,12)=A(J,8)*COS(A(J,7)*.017453)-A(J,9)*
             *   SIN(A(J,7)*.017453)
              A(J,13)=(A(J,12)/A(J,6))*100.0
      100     CONTINUE
              WRITE(LO,6)
      6       FORMAT(1H ,34X,'CALCULATIONS',//,36X,'TABLE 1'/)
              WRITE(LO,7)
      7       FORMAT(1H ,9X,'ACTUAL',5X,'INDICATED',4X,'MAGNETIC',6X,
             *   'ACTUAL',2X,'BEARING',4X,'EAST',4X,'NORTH')
```

(Continued)

```
      WRITE(LO,8)
8     FORMAT(1H ,'LEG',X,2(3X,'COORDINATE'),2X,'DIFFERENCE',4X,
     *  'DISTANCE',2X,'ANGLE',4X,'ERROR'3X,'ERROR'/)
      WRITE(LO,9)C(1),(A(1,J),J=1,9)
9     FORMAT(1H ,A4,F7.0,'-',F5.0,F7.0,'-',F5.0,F9.1,7X,F6.0,
     *   F9.1,F10.1,F8.1)
      WRITE(LO,9)C(2),(A(2,J),J=1,9)
      WRITE(LO,9)C(3),(A(3,J),J=1,9)
      WRITE(LO,9)C(4),(A(4,J),J=1,9)
      WRITE(LO,10)
10    FORMAT(1H ,/,37X,'TABLE 2',/)
      WRITE(LO,11)
11    FORMAT(1H ,13X,'ALONG TRACK ERROR',19X,'CROSS TRACK ERROR')
      WRITE(LO,12)
12    FORMAT(1H ,'LEG',9X,2('(M)',13X,'(%)',17X)/)
      WRITE(LO,13)C(1),(A(1,J),J=10,13)
13    FORMAT(1H ,A4,7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2)
      WRITE(LO,13)C(2),(A(2,J),J=10,13)
      WRITE(LO,13)C(3),(A(3,J),J=10,13)
      WRITE(LO,13)C(4),(A(4,J),J=10,13)
      DO 200 J=1,4
      B1=A(J+(-1)**(J+1),2)-A(J,2)
      B2=A(J+(-1)**(J+1),1)-A(J,1)
      IF(B2.LT.0.0)GOTO 370
      B(J,4)=90.0-ATAN(B1/B2)*57.2958+A(J,5)
      GOTO 375
370   B(J,4)=270.0-ATAN(B1/B2)*57.2958+A(J,5)
375   B(J,1)=A(J,4)-A(J,2)
      B(J,2)=A(J,3)-A(J,1)
      IF(B(J,2).LT.0.0)GOTO 400
      B(J,3)=90.0-ATAN(B(J,1)/B(J,2))*57.2958+A(J,5)
      IF(B(J,3).LT.360.0)GOTO 405
      B(J,3)=B(J,3)-360.0
      GOTO 405
400   B(J,3)=270.0-ATAN(B(J,1)/B(J,2))*57.2958+A(J,5)
      IF(B(J,3).LT.360.0)GOTO 405
      B(J,3)=B(J,3)-360.0
405   B(J,5)=B(J,3)-B(J,4)
200   CONTINUE
      WRITE(LO,14)
14    FORMAT(1H  )
      WRITE(LO,15)
15    FORMAT(1H ,36X,'TABLE 3'/)
      WRITE(LO,16)
16    FORMAT(1H ,'LEG',3X,'DIRECTION',5X,'DEL NORTH',4X,'DEL EAST',
     *   3X,'THETA',5X,'THETA TRUE',3X,'ERROR'/)
      WRITE(LO,17)C(1),(B(1,J),J=1,5)
17    FORMAT(1H ,A4,4X,'SOUTH',8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
      WRITE(LO,18)C(2),(B(2,J),J=1,5)
18    FORMAT(1H ,A4,4X,'NORTH',8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
      WRITE(LO,19)C(3),(B(3,J),J=1,5)
19    FORMAT(1H ,A4,4X,'EAST',9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
      WRITE(LO,20)C(4),(B(4,J),J=1,5)
20    FORMAT(1H  ,A4,4X,'WEST',9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)

      WRITE(LO,21)(B(2,5)-B(1,5))/2.0
21    FORMAT(1H  ,'ERROR-N/S',5X,F10.2/)
      WRITE(LO,22)(B(3,5)-B(4,5))/2.0
22    FORMAT(1H ,'ERROR-E/W',5X,F10.2/)
      WRITE(LO,23)(B(1,5)+B(2,5)+B(3,5)+B(4,5))/4.0
23    FORMAT(1H ,'INDEX ERROR',5X,F10.2)
      END
```

APPENDIX D

FORTRAN PRINTOUT

CALCULATIONS

TABLE 1

LEG	ACTUAL COORDINATE	INDICATED COORDINATE	MAGNETIC DIFFERENCE	ACTUAL DISTANCE	BEARING ANGLE	EAST ERROR	NORTH ERROR
1-2	5040- 2190	4840- 833	10.9	14572	198.0	100.0	1550.0
2-1	4860- 744	5010- 2124	11.0	14572	18.1	-100.0	-1550.0
1-3	5040- 2190	3187- 1935	10.7	19785	270.6	2050.0	70.0
3-1	3092- 1844	4930- 2274	11.0	19785	90.9	-2050.0	-70.0

TABLE 2

LEG	ALONG TRACK ERROR (M)	ALONG TRACK ERROR (%)	CROSS TRACK ERROR (M)	CROSS TRACK ERROR (%)
1-2	-1505.1	-10.33	383.8	2.63
2-1	-1504.4	-10.32	386.4	2.65
1-3	-2049.1	-10.36	92.5	0.47
3-1	-2048.6	-10.35	103.2	0.52

TABLE 3

LEG	DIRECTION	DEL NORTH	DEL EAST	THETA	THETA TRUE	ERROR
1-2	SOUTH	-1357.0	-200.0	199.3	198.0	1.3
2-1	NORTH	1380.0	150.0	17.2	18.1	-0.9
1-3	EAST	-255.0	-1853.0	272.9	270.6	2.2
3-1	WEST	430.0	1838.0	87.8	90.9	-3.1

ERROR-N/S -1.09

ERROR-E/W 2.67

INDEX ERROR -0.12